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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF CAUSEY DAM OUTLET WORKS--WEBER BASIN PROJECT, UTAH

Hydraulics Branch Report No. Hyd. 496

DIVISION OF RESEARCH

OFFICE OF CHIEF ENGINEER
DENVER, COLORADO

April 5, 1963

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Denver, Colorado
April 5, 1963

Laboratory Report No. Hyd. 496
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Subject: Hydraulic model studies of Causey Dam Outlet Works--Weber Basin Project, Utah

PURPOSE

The purpose of the study was to observe the hydraulic operating characteristics and energy dissipating efficiency of the hydraulic jump stilling basin, to determine the pressures at critical points throughout the structure, and to determine the pressures and hydraulic losses in the symmetrical wye branch.

CONCLUSIONS

1. Flow on the chute, in the stilling basin, and in the downstream channel was satisfactory for maximum discharges with both gates 100 percent open, Figure 6, and for gate openings of 75, 50, and 25 percent with the maximum reservoir elevation.

2. Operation with one gate fully opened and the other gate closed, under maximum head, Figure 6, exhibited adverse surging within the basin and a possibility of erosion at the downstream end of the basin, Figure 8.

3. Erosion of material in the downstream channel, Figure 8, was negligible except for operation with one gate closed as mentioned in Paragraph 2.

4. No extreme subatmospheric pressures or excessively high dynamic pressures were found in the wye branch, sloping chute, or on the stilling basin training walls.

5. Waves in the downstream channel had a maximum height of approximately 1.5 to 1.7 feet occurring for the high tailwater (maximum spillway flow) with maximum flow through either one or two gates. With low tailwater (no flow through the spillway)

the maximum wave heights were reduced to about 0.5 foot. Measurement of waves immediately adjacent to and outside the basin training walls indicated a maximum wave height of about 1.3 feet for the high tailwater.

6. The minimum safety margin between sweepout tailwater and low tailwater was found to be about 3.6 feet for operation with one gate opened 100 percent and the other gate closed with normal losses in the system, Figure 12. With both gates opened 100 percent, the safety factor was 7.0 feet. In both cases the sweepout tailwater elevation was below the actual bottom elevation of the channel, indicating that sweepout was physically impossible for the given configuration of the channel.

7. A minimum subatmospheric pressure of 7.7 feet of water occurred in the crotch of the wye branch with flow through one leg only, Figure 14. Pressures were above atmospheric for symmetrical operation. Losses in one leg of the branch including the horizontal bend and transition varied from 1.32 times the upstream velocity head (with all flow through the measured leg) to 0.29 times the upstream velocity head with equal flow through each leg, Figure 15.

INTRODUCTION

Causey Dam, a feature of the Weber Basin Project in Utah, is located on the south fork of the Ogden River at its confluence with Causey Creek about 24 miles east of Ogden, Figure 1. The dam is an earthfill embankment about 900 feet long and approximately 200 feet high above the riverbed. The principal hydraulic features are a side channel spillway located in the right abutment and a slide gate controlled outlet works located in the left abutment, Figure 2. The model studies described herein were made to determine the operating characteristics of the outlet works, Figure 3.

Flow from the outlet works, controlled by two 2-foot 9-inch square high-pressure slide gates, discharges into a divided 2 to 1 sloping diverging chute, into the hydraulic jump stilling basin, and then into the river channel. The gate flow is divided by a symmetrical wye branch located a short distance upstream from the gate section. The outlet works is designed to carry a maximum discharge of 783 cubic feet per second.

THE MODEL

The 1 to 11 scale model of Causey Dam outlet works consisted of the wye branch, the two high-pressure slide gates, the sloping chute, the hydraulic jump stilling basin, and a portion of the downstream channel. An overall view of the completed model is shown in Figure 4.

The chute floor, stilling basin, and center dividing wall were constructed of plywood and the warped surfaces of the chute training walls and the second-stage construction on the center dividing wall were formed with concrete. The stilling basin included chute blocks and a dentated end sill and the downstream channel was formed from sand with an average size of 0.8 millimeter.

Piezometers were placed in the wye branch, on the floor and one wall of the chute, and on one wall of the stilling basin to investigate the possible occurrence of adverse subatmospheric pressures or unusually high dynamic pressures.

Water was supplied to the model through a baffled manifold located approximately 5 diameters upstream from the wye branch and connected directly to the laboratory supply system. Discharges through the model were measured with volumetrically calibrated Venturi meters which are permanent laboratory installations.

Since the reservoir area and outlet works conduit were not included in the model, proper flow conditions in the model were established by setting the appropriate pressure head computed at a measuring station located approximately 1 diameter upstream from the start of the wye branch. The measuring station consisted of pressure taps in the sides and bottom of the conduit connected to a common lead. The gates were adjusted to give the proper pressure head for a given discharge.

The tailwater was controlled with an adjustable tailgate and tailwater elevations were measured with a staff gage located in the center of the river channel at approximately Station 15+11. Tailwater elevation settings were determined from the rating curve, Figure 5.

THE INVESTIGATION

The investigation was concerned primarily with determing the energy dissipating efficiency and hydraulic operating characteristics of the hydraulic jump stilling basin for the maximum design discharge of 783 second-feet (normal friction losses in the system; Manning's "n" = 0.012 for steel and 0.013 for concrete) with both gates 100 percent open. Additional observations were made with one gate opened 100 percent and the other closed under the maximum head and for both one-gate and two-gate operation for partial gate openings (75, 50, and 25 percent) under the maximum head. All investigations were made for two tailwater conditions. The high tailwater condition corresponded to combined operation of the spillway and outlet works and the low tailwater condition represented operation of the outlet works alone, Figure 5. For the maximum reservoir elevation of 5698.1 at which the spillway and outlet works are both operating, the outlet works discharge is 783 second-feet. At reservoir elevation 5692 the spillway is not operating and the outlet works discharges 770 second-feet. Since this difference is only about 2 percent, operation was evaluated only for the discharge of 783 cubic feet per second, even though tailwater elevations for both conditions were used.

Pressures in the crotch of the wye branch were determined for symmetrical and asymmetrical flows and hydraulic loss coefficients were computed for varying ratios of discharge in each leg of the branch.

Chute and stilling basin pressures and tailwater sweepout data were also taken for maximum discharges of 985 second-feet (two gates) and 620 second-feet (one gate) which correspond to the maximum reservoir elevation with minimum losses in the system, using a Manning's "n" value of 0.008 for both concrete and steel. These conditions will probably exist only if the maximum flood occurs very early in the life of the structure when the conduits are new. Therefore, for purposes of this model study, operation with discharges corresponding to the normal losses was emphasized.

The Preliminary Stilling Basin--Recommended

Initial observation of the preliminary stilling basin showed that the operation was satisfactory for the maximum discharge of 783 cubic feet per second with both gates opened 100 percent, Figures 6 and 8, and for partial gate openings of 75, 50, and 25 percent with either one gate or two gates open. Flow downstream from the gate was smooth and well distributed across the entire width of the chute. The hydraulic jump was confined within the basin and velocities at the downstream end of the basin were low. Operation of the stilling basin with one gate 100 percent open and the other gate closed was less satisfactory especially for the high tailwater at which a strong surging occurred within the basin and the flow sometimes overtopped the walls, Figure 6.

At a tailwater elevation slightly below the maximum, either for one-gate or two-gate operation, the gates were alternately submerged then unsubmerged, causing a periodical "slamming" action in the gate chamber. Air vents installed in the downstream gate frames showed little demand for air and provided no noticeable improvement in the flow conditions. If this particular tailwater condition should occur, return flow between the top of the jet and roof of the gate frame will alleviate any possible destructive action. Therefore, air vents will not be installed in the prototype structure.

The studies showed that no basin modifications were necessary and the preliminary chute and stilling basin were recommended for prototype construction, Figure 7.

Erosion Test

The river channel downstream from the stilling basin was shaped with sand with an average size of 0.8 millimeter. The channel was subjected to 4 hours' operation (equivalent to about 13 hours prototype operation) at the maximum discharge of 783 second-feet, tailwater elevation 5503.0, with both gates 100 percent open, Figure 8. No apparent erosion had occurred at the completion of this test.

The channel was reshaped and subjected to 4 hours' model operation at a discharge of 554 second-feet, tailwater elevation 5502.5, with the right gate 100 percent open and the other gate completely closed, Figure 8. At the completion of this test the effect of asymmetrical operation was noticeable in the downstream channel. Material was deposited on the downstream side of the dentated end sill and inside the left half of the basin. No riprap suitability test was made but the erosion test indicated that asymmetrical operation with discharge through one gate fully opened under maximum head might have some undesirable erosive effects.

Pressure Investigations

Water manometer pressures were determined in the chute and stilling basin to investigate the possible occurrence of adverse subatmospheric pressures or excessively high dynamic pressures. Figure 9 shows the piezometer locations, a tabulation of the water manometer pressures, and the pressure profiles plotted from the tabulated data. The table and pressures profiles indicate that no adverse pressures existed in the structure.

Several piezometers on the chute in the region of the toe of the hydraulic jump were checked to determine the degree of pressure fluctuation. Previous model studies have indicated large fluctuations in this region. The pressures were measured with electronic cells and recorded instantaneously by a direct writing oscillograph. A minimum subatmospheric pressure of 15.9 feet of water was observed at Piezometer 5 on the chute wall just above the floor; however, this pressure occurred less than 1 percent of the time and was considered to have no possible damaging effects. Piezometer 6, on the floor of the chute near the wall, also showed a slight subatmospheric pressure. Piezometers 1, 2, and 3, located immediately downstream from the gate frame, indicated pressures above atmospheric with little fluctuation. Instantaneous dynamic pressures are shown in Table 1.

Instantaneous dynamic pressures were also measured on the stilling basin training walls for use in the structural design of the walls. The pressures are shown for Piezometers 17, 18, 19, 20, and 21 in Table 1. Fluctuations were greater for the discharge of 554 second-feet through one gate at maximum tailwater elevation. This is a further indication of the surging which occurs in the basin for this operating condition.

Chute and stilling basin water manometer pressures were read for discharges of 985 and 620 cubic feet per second which could occur with minimum losses in the system. These pressures, Figure 10, compare quite closely with those observed for the maximum discharges with normal losses in the system, Figure 9.

Pressures were also measured in the wye branch and are included in a subsequent section of this report.

Water Surface Profiles

Figure 11 shows water surface profiles measured along the walls of the chute and stilling basin. The water surface profiles, when compared with the pressure profiles of Figure 9, clearly show the bulking effect of air entrainment. The profiles for symmetrical operation at the maximum discharge of 783 cubic feet per second are applicable to both training walls and the center dividing wall of the basin. The profiles, showing both the maximum and minimum fluctuation of the water surface, indicate that the flow is confined within the basin for this discharge.

Profiles for single-gate operation, with a discharge of 554 cubic feet per second, were determined for both sides of the basin and may be used to estimate the forces acting on the center dividing wall. The profiles show that the water surface in the left (no flow) side of the stilling basin overtops the training wall due to the surging flow for the high tailwater condition. However, the overtopping occurs near the downstream end of the basin and the excess flow falls harmlessly into the pool outside the training wall.

Wave Measurements

The highest waves in the downstream channel occurred for high tailwater conditions for either one-gate or two-gate operation and were found to have a maximum height of approximately 1.5 to 1.7 feet along the right bank of the channel at approximately Station 14+50. Waves occurring with the low tailwater condition were less than 0.5 foot in height. Waves along the outside of the basin training walls were more accurately measured using a variable capacitance wave probe and were found to vary from about 0.6 foot for two-gate operation to about 1.3 feet for one-gate operation. These data were used in conjunction with simultaneously measured pressure fluctuations in the structural design of the walls.

Tailwater Sweepout Tests

Tailwater sweepout tests were conducted to determine the safety margin between the low tailwater elevation and the tailwater elevation at which the hydraulic jump begins to move downstream in the stilling basin. The sweepout tailwater curve shown in Figure 12 represents the points at which the chute blocks first become exposed for different gate openings at maximum reservoir elevation. Complete sweepout at which the jump forms beyond the end of the basin occurred when the tailwater was lowered an additional 1 foot to 2 feet. Figure 12 indicates minimum safety margins of 7.0 feet for two-gate operation and 3.6 feet for one-gate operation. In both cases the sweepout elevation is below the channel bottom elevation of 5501.0, indicating that sweepout is physically impossible for the given channel configuration.

Sweepout data taken for the maximum discharges of 985 and 620 cubic feet per second indicated sweepout would occur at tailwater elevations 3 feet higher than those for discharges of 783 and 554 cubic feet per second. This reduces the corresponding safety margins to 4.4 feet and 0.7 foot, respectively. However, as previously mentioned, complete sweepout occurs at an elevation 1 foot to 2 feet lower than that at which the chute blocks become exposed. Table 2 gives a summary of sweepout elevations for the maximum discharges.

Wye-branch Studies

The symmetrical wye branch, Figure 13, consisted of the branch proper, horizontal bends, circular-to-square transitions, and vertical square elbows. Piezometers were placed in the crotch of the branch to investigate the possible occurrence of severe subatmospheric pressures. Pressure taps were located approximately 1 diameter upstream from the start of the wye and at the downstream ends of the transitions to determine the hydraulic losses in the structure.

Figure 14 shows the location of piezometers in the wye crotch and a table of water manometer pressures for both two-gate and one-gate operation, 100 percent gate opening, and maximum reservoir elevation. All water manometer pressures were found to be above atmospheric. Piezometer 27, immediately downstream from the crotch, was further investigated using electronic pressure cells which measure the instantaneous dynamic pressure fluctuations. The minimum instantaneous pressure was 7.7 feet of water below atmospheric, shown in the table in Figure 14. This pressure is well above the cavitation range.

Hydraulic losses through one leg of the branch were measured for various percentages of the total flow being diverted through the leg. The loss factor K, Figure 15, is based on the velocity head in the pipe upstream from the branch and includes the loss in the horizontal bends and the circular-to-square transitions. The following example illustrates the use of the loss factor curve. Assume that the discharge through one leg of the branch has been determined such that:

$$\frac{Q_B}{Q_T} = 70 \text{ percent}$$

where

Q_B = discharge in right leg

Q_T = total discharge

From Figure 14, K = 0.705; therefore, loss in the right leg of branch is

$$h = K\frac{V2}{2g} = 0.705\frac{V2}{2g}$$

where $\frac{V^2}{2g}$ is the velocity head upstream from the branch.

Similarly, to determine the loss in the left leg of the branch, $\frac{Q_A}{Q_T}$ = 30 percent, K = 0.355, and $h = 0.355 \frac{V^2}{2g}$.

The loss factor is lowest with symmetrical flow through the branch or when $\frac{Q_A}{Q_T}$ = 50 percent:

$$K = 0.290 \text{ and } h = 0.290 \frac{V^2}{2g}$$

With one gate closed and all the flow passing through one leg, or $\frac{Q_A}{Q_T}$ = 100 percent, the loss factor, K = 1.320, and $h = 1.320 \frac{V^2}{2g}$.

Table 1

INSTANTANEOUS DYNAMIC PRESSURES IN THE CHUTE AND STILLING BASIN--PROTOTYPE FOOT OF WATER

Discharge	Tailwater elevation	Piezometer No.	Maximum pressure	Minimum pressure	Average pressure
*783	5503.0	1	4.7	1.9	3.9
		2	4.8	2.6	3.7
		3	4.6	2.4	3.6
		5	31.9	-11.5	7.7
		6	22.0	-1.1	11.0
*783	5510.5	17	15.3	11.7	13.6
		18	24.0	20.2	22.8
		19	9.6	7.2	8.5
		20	17.4	14.4	16.1
		21	25.0	21.8	23.3
**554	5502.5	1	6.6	2.7	4.4
		2	6.8	3.3	4.9
		3	4.9	1.2	4.0
		5	31.0	-15.9	1.7
		6	23.1	-2.2	4.4
**554	5510.3	17	16.3	7.7	13.1
		18	25.3	17.4	21.8
		19	8.9	4.5	8.0
		20	18.1	11.9	15.4
		21	25.7	21.7	23.9

*Both gates opened 100 percent at maximum reservoir elevation.
**Right gate 100 percent open. Left gate closed. Piezometer locations shown on Figure 9.

Table 2

SWEEPOUT TAILWATER ELEVATIONS
FOR MAXIMUM DISCHARGES

Discharge*	Sweepout tailwater** elevation	Estimated complete sweepout
783	5496	5494
554	5499	5498
985	5499	5498
620	5502	5500

*783--Both gates 100 percent open. Normal losses in system.
554--Right gate 100 percent open. Left gate closed. Normal losses in system.
985--Both gates 100 percent open. Minimum losses in system.
620--Right gate 100 percent open. Left gate closed. Minimum losses in system.
**Where chute blocks first become exposed.

FIGURE 1
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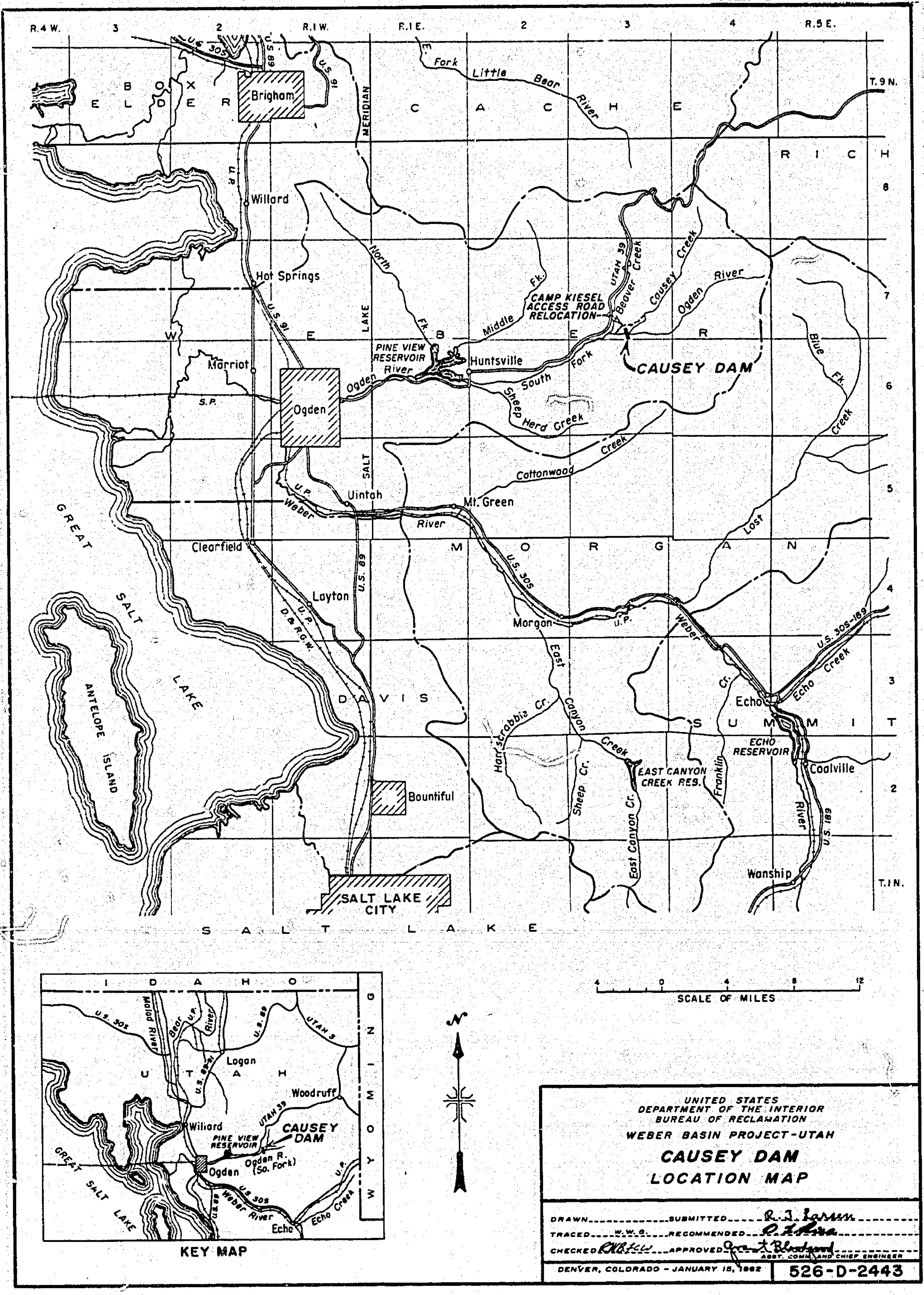

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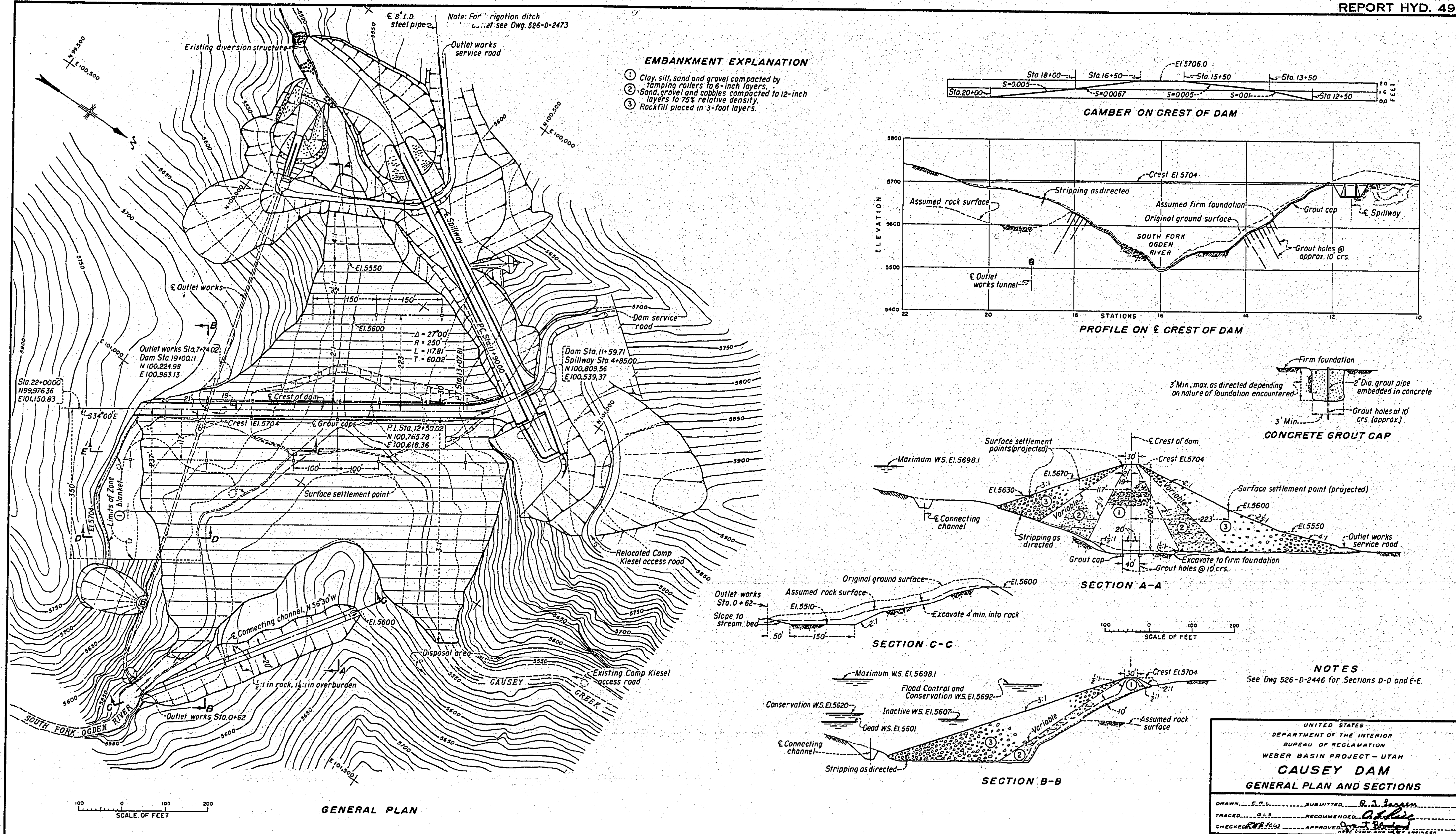
WEBER BASIN PROJECT-UTAH

CAUSEY DAM
LOCATION MAP

DRAWN........ SUBMITTED R. J. Larsen
TRACED W.W.G. RECOMMENDED
CHECKED RWB/cw APPROVED Grant Bloodgood
ASST. COMM. AND CHIEF ENGINEER

DENVER, COLORADO - JANUARY 15, 1962 | 526-D-2443



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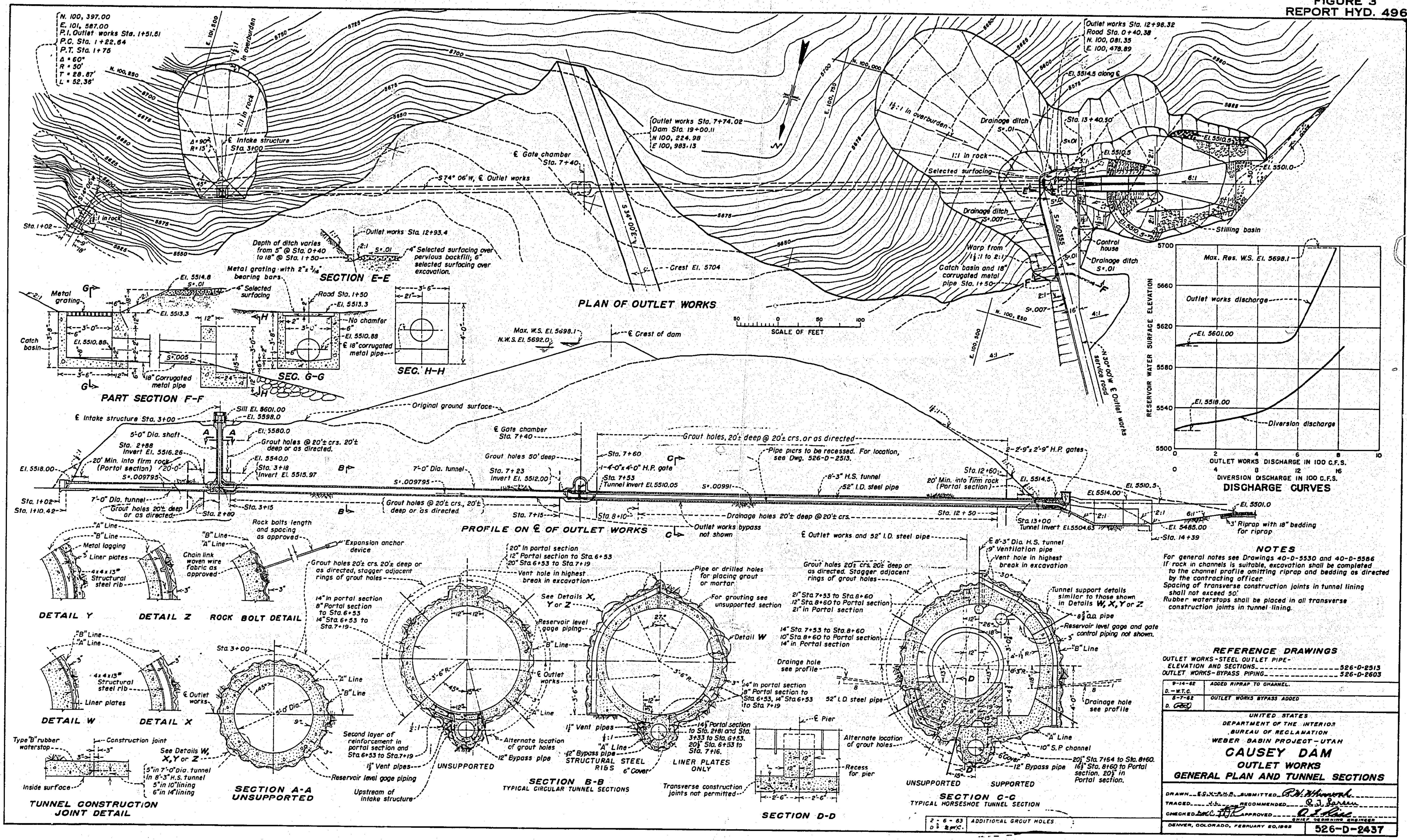
WEBER BASIN PROJECT – UTAH

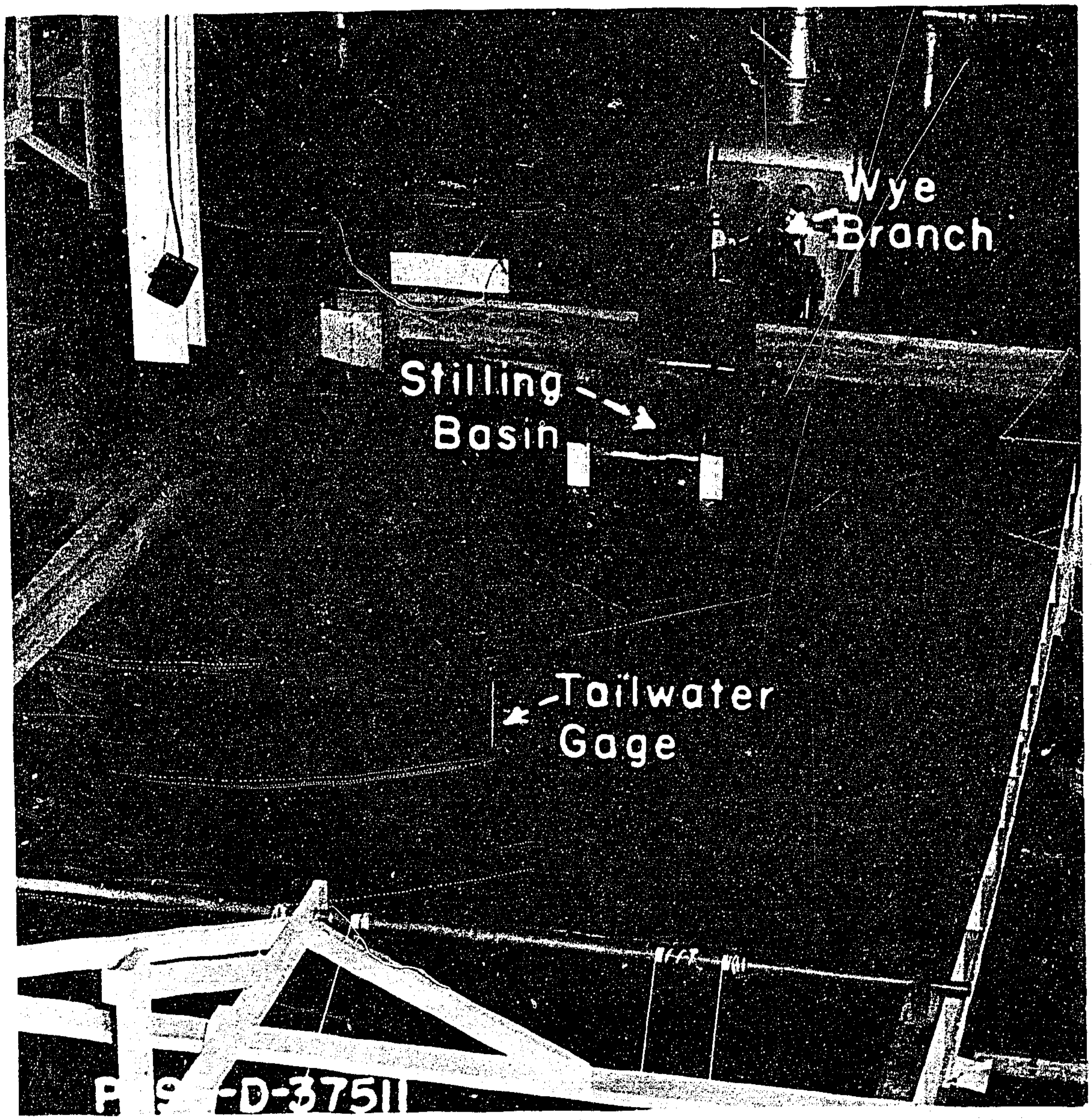
CAUSEY DAM

GENERAL PLAN AND SECTIONS

DENVER, COLORADO, FEBRUARY 20, 1962 — 526-D-2445

FIGURE 3
REPORT HYD. 496

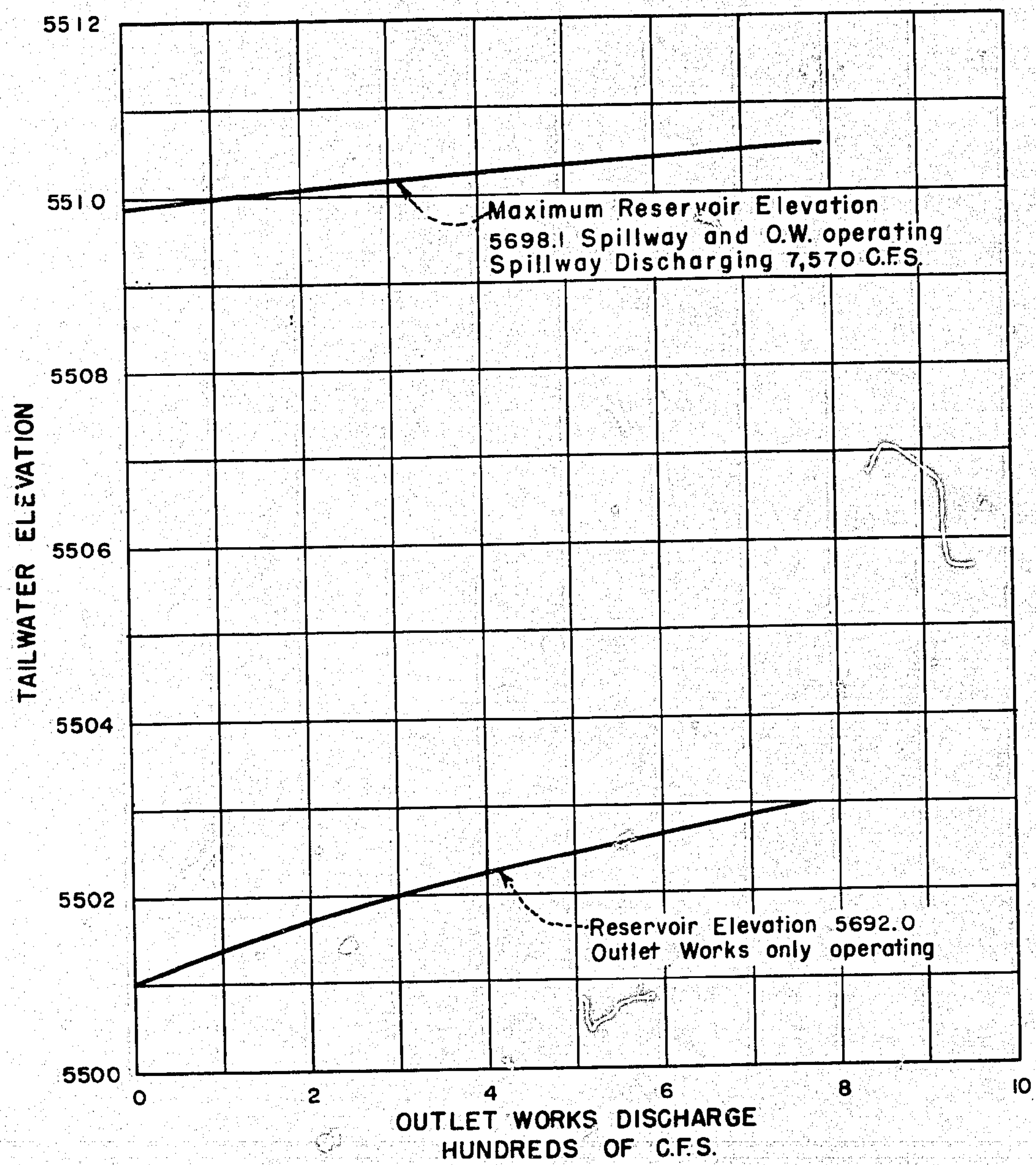




CAUSEY DAM OUTLET WORKS

1:11 Scale Model

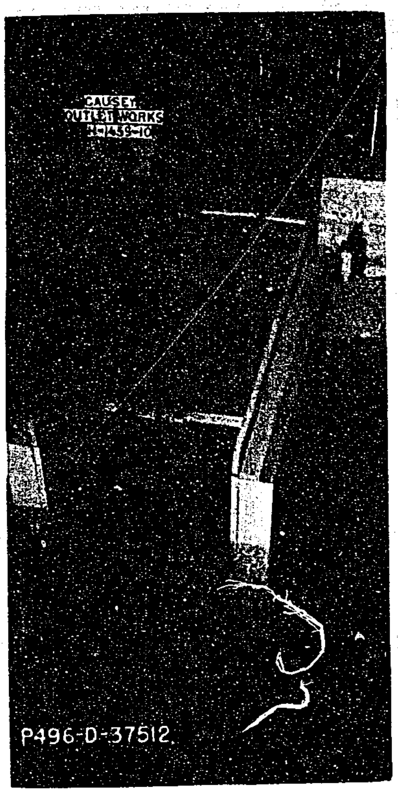
Completed Model

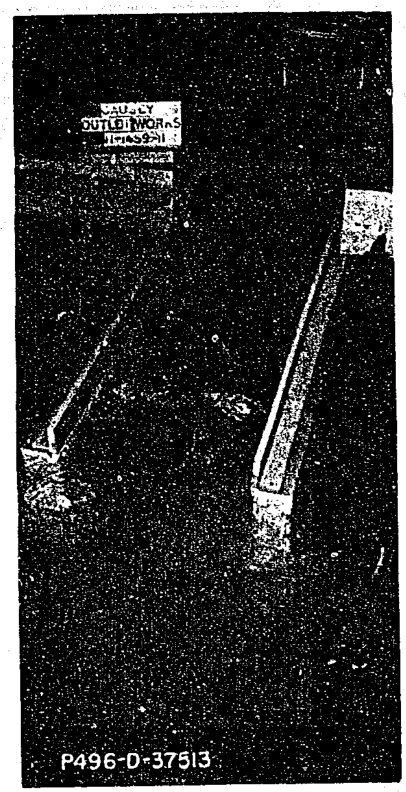


CAUSEY DAM OUTLET WORKS

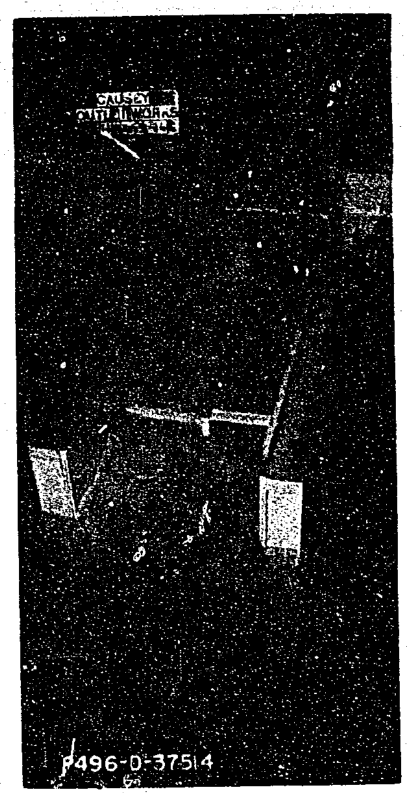
1:11 SCALE MODEL

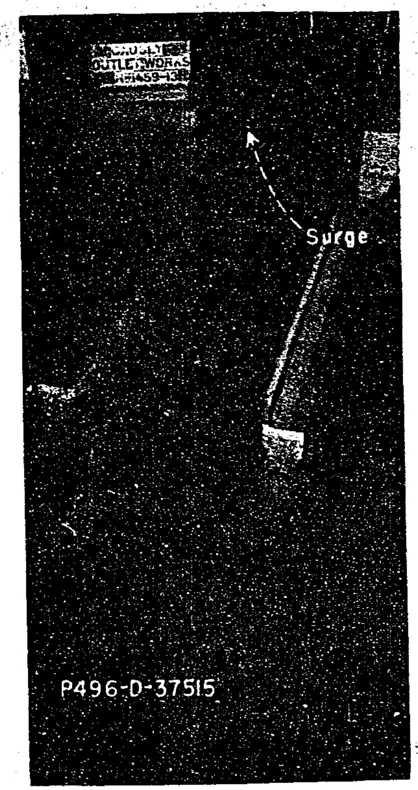
TAILWATER CURVES





Tailwater El. 5503.0 Tailwater El. 5510.5
Q=783 cfs, both gates 100% open





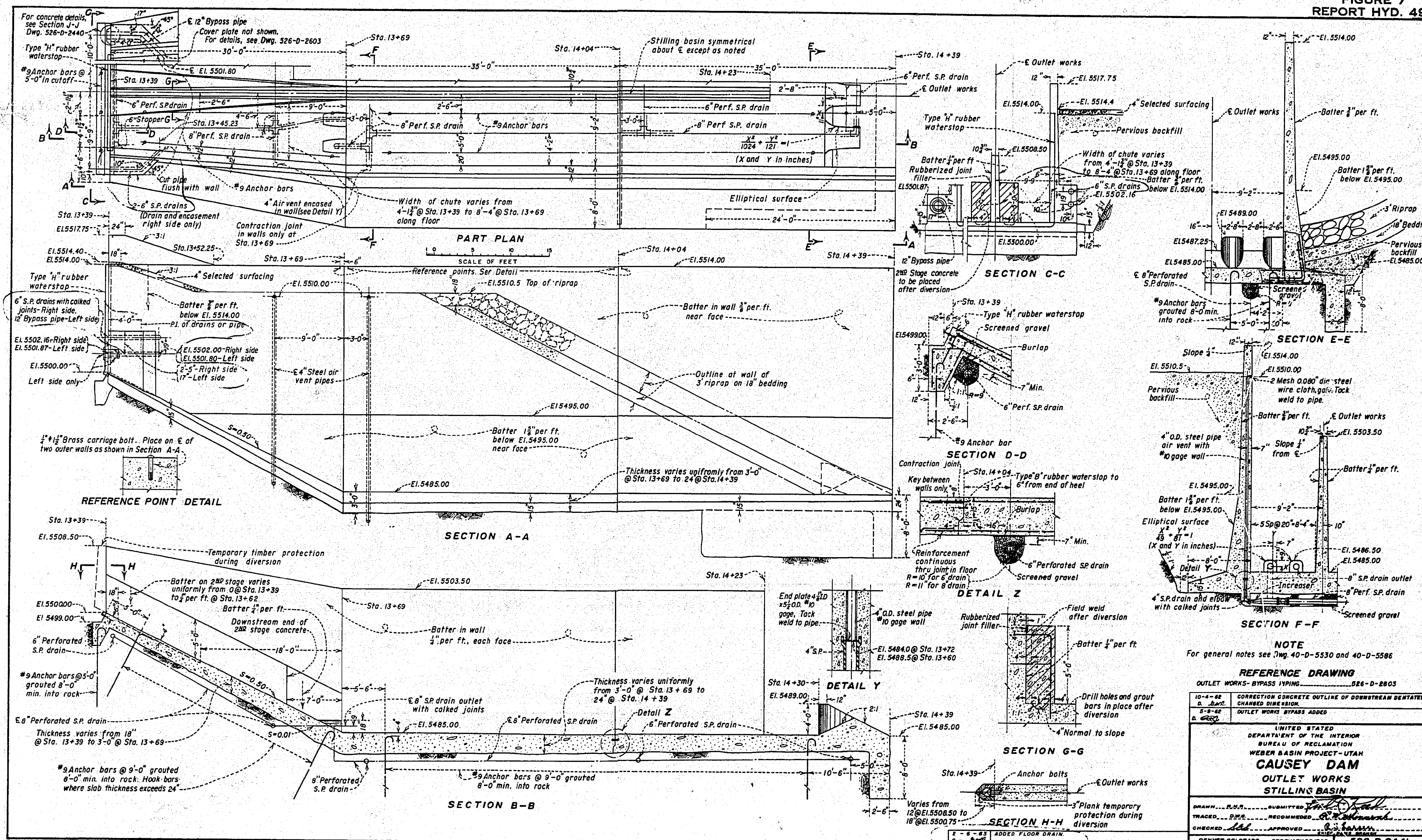
Tailwater El. 5502.5 Tailwater El. 5510.3
Q=554 cfs, right gate only 100% open

CAUSEY DAM OUTLET WORKS

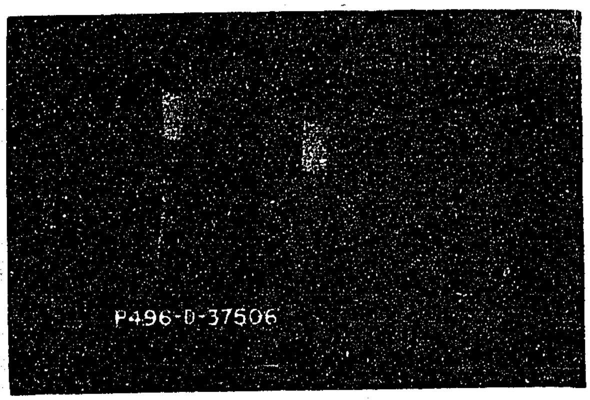
1:11 Scale Model

Flow Conditions in the Stilling Basin

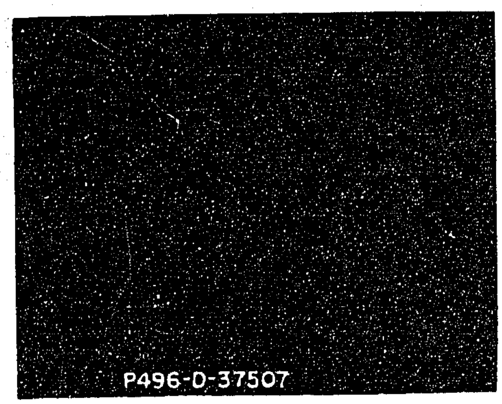
FIGURE 7
REPORT HYD. 496



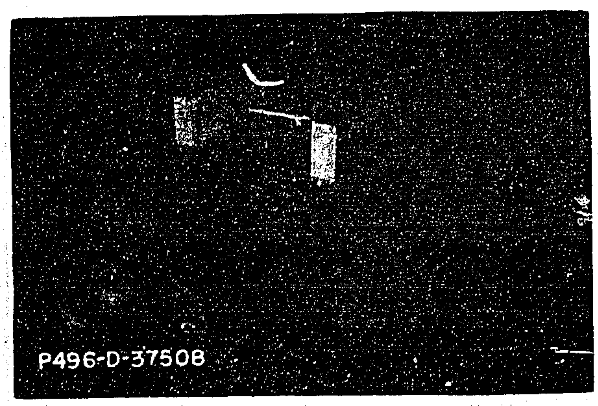
Sand bed before erosion



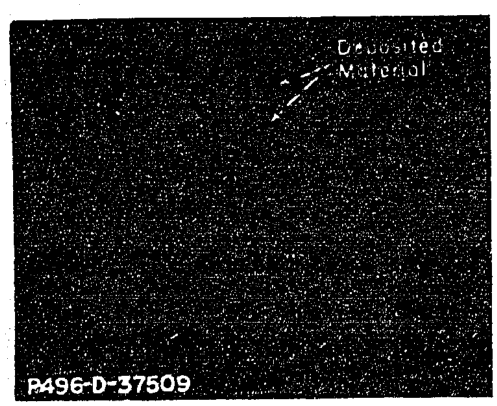
Q=783 cfs, both gates 100% open, tailwater elevation 5503.0



After 4 hour's operation with Q=783 cfs



Q=554 cfs, right gate 100% open, left gate closed, tailwater elevation 5502.5

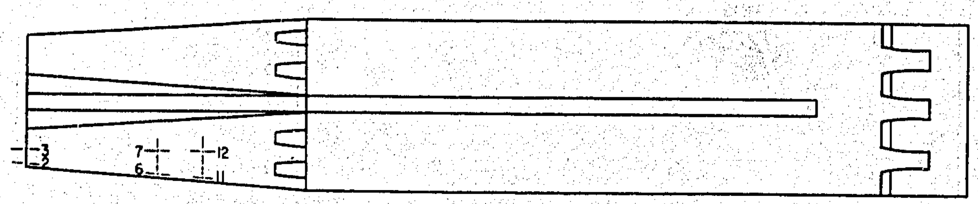


After 4 hour's operation with Q=554 cfs

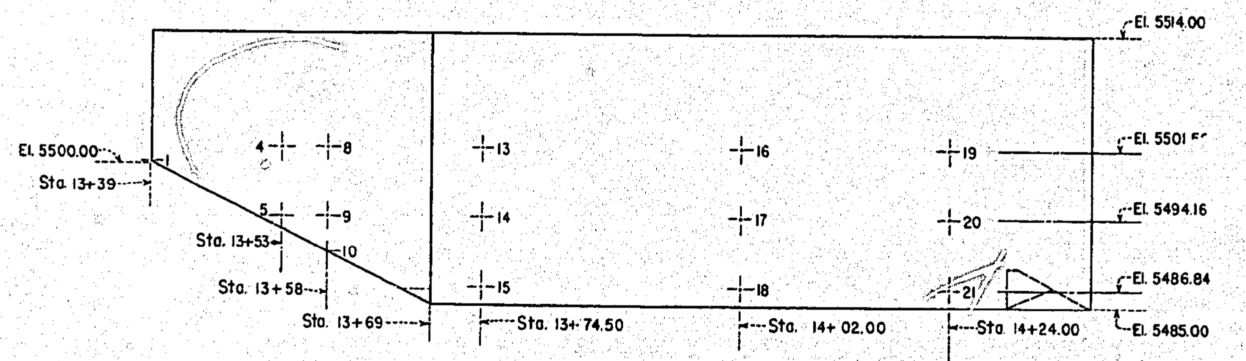
CAUSEY DAM OUTLET WORKS

1:11 Scale Model

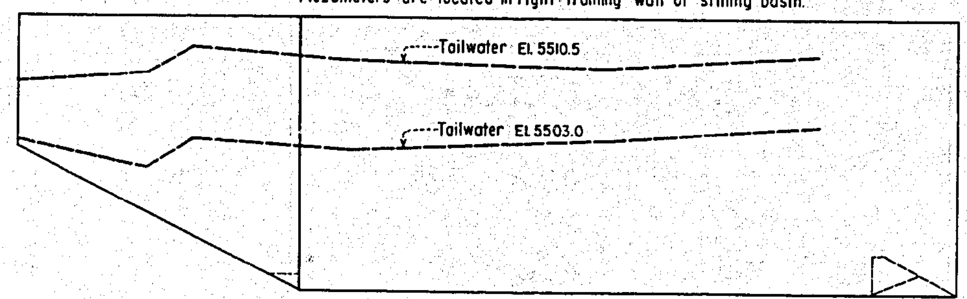
Erosion Tests



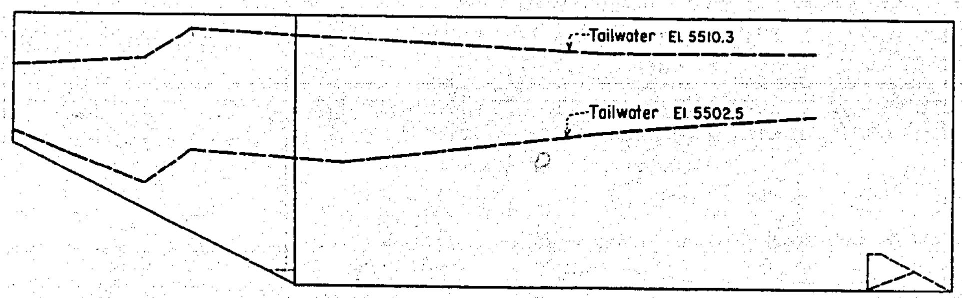
PIEZOMETER LOCATIONS
PLAN



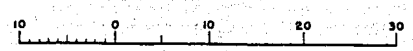
PIEZOMETER LOCATIONS
ELEVATION
Piezometers are located in right training wall of stilling basin.



PRESSURE PROFILES
Q = 783 C.F.S.



PRESSURE PROFILES
Q = 554 C.F.S.



WATER MANOMETER PRESSURES--PROTOTYPE FEET OF WATER

Q=783 C.F.S. Both gates 100% open

PIEZOMETER NUMBER	TAILWATER ELEVATION 5503.0			TAILWATER ELEVATION 5510.5		
	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE
1	0.6	0.6	0.6	7.8	6.1	7.0
2	6.7	6.5	6.6	12.5	11.1	11.8
3	4.0	3.9	4.0	10.1	9.2	9.7
4	——	——	——	7.2	6.5	6.9
5	5.2	4.3	4.8	15.1	14.1	14.6
6	7.6	6.3	7.0	16.7	15.3	16.0
7	8.1	7.2	7.7	16.4	15.1	15.8
8	——	——	——	7.0	6.6	6.8
9	5.4	3.5	4.5	15.0	13.2	14.1
10	10.9	9.6	10.3	20.5	19.5	20.0
11	13.1	11.3	12.2	21.7	20.4	21.1
12	11.1	9.8	10.5	20.9	19.9	20.5
13	——	——	——	7.4	6.3	7.0
14	6.1	4.3	5.2	14.9	13.6	14.3
15	13.3	12.0	12.7	23.1	22.0	22.6
16	0.6	0.1	0.3	7.6	6.4	7.0
17	7.7	6.2	7.0	15.3	13.5	14.4
18	14.9	13.1	14.0	22.2	21.3	21.8
19	1.2	1.0	1.1	8.0	7.6	7.8
20	8.1	7.7	7.9	15.4	14.4	14.9
21	15.6	15.4	15.5	23.3	23.1	23.2

Q=554 C.F.S.; Right gate 100% open, left gate closed

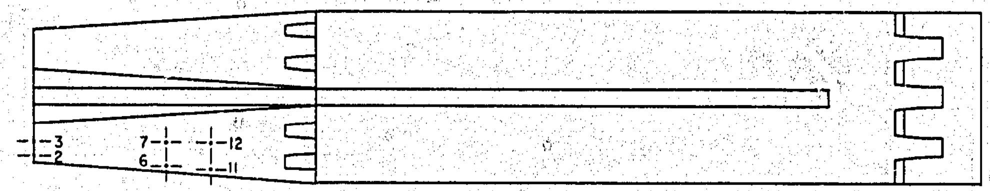
PIEZOMETER NUMBER	TAILWATER ELEVATION 5502.5			TAILWATER ELEVATION 5510.3		
	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE
1	1.5	1.0	1.3	9.5	7.3	8.4
2	15.0	10.9	13.0	16.7	14.0	15.4
3	5.8	4.5	5.2	12.1	10.6	11.4
4	——	——	——	8.0	6.9	7.5
5	3.9	1.8	2.9	16.7	15.6	16.2
6	7.4	4.7	6.1	19.5	18.2	18.9
7	9.9	6.8	8.4	19.9	18.4	19.2
8	——	——	——	8.6	7.9	8.3
9	4.0	2.3	3.2	15.8	13.5	14.7
10	9.7	7.9	8.8	22.3	21.3	21.8
11	11.6	9.2	10.4	23.5	22.4	23.0
12	10.3	9.1	9.7	22.6	21.3	22.0
13	——	——	——	8.5	7.9	8.2
14	4.3	2.1	3.2	15.7	14.3	15.0
15	12.1	10.6	11.4	25.1	24.1	24.6
16	1.0	0.1	0.6	8.5	7.5	8.0
17	7.0	4.3	5.7	15.6	14.6	15.1
18	16.2	13.2	14.7	23.4	22.7	23.1
19	2.4	2.4	2.4	9.2	8.5	8.9
20	10.7	10.2	10.5	16.0	15.4	15.7
21	16.8	16.8	16.8	23.8	22.8	23.3

Pressure measured above piezometer opening.
Blank spaces indicate piezometer is above the water surface.

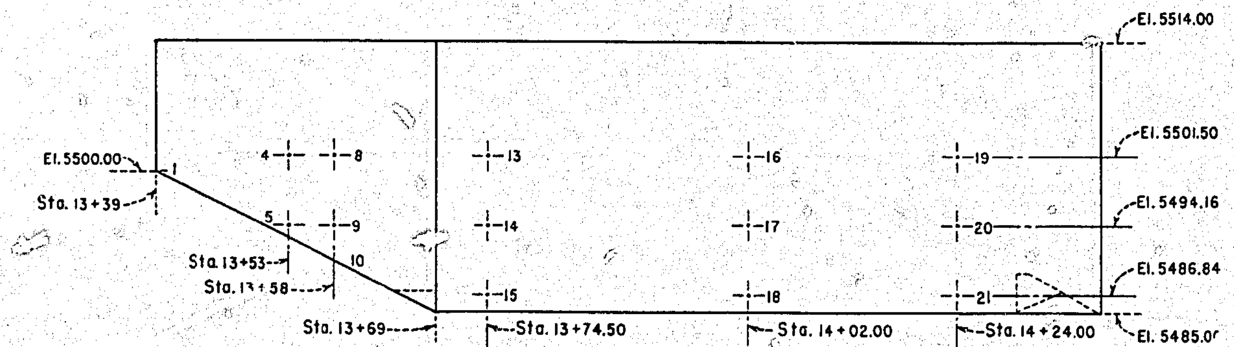
CAUSEY DAM OUTLET WORKS

1:11 SCALE MODEL

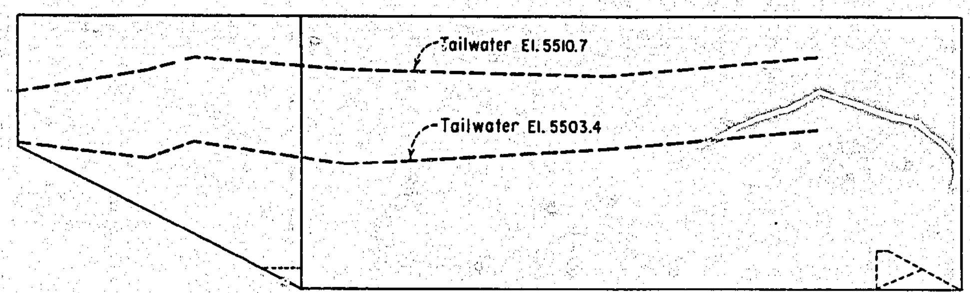
PIEZOMETER LOCATIONS, PRESSURES, AND PRESSURE PROFILES
MAXIMUM DISCHARGES WITH NORMAL LOSSES IN SYSTEM



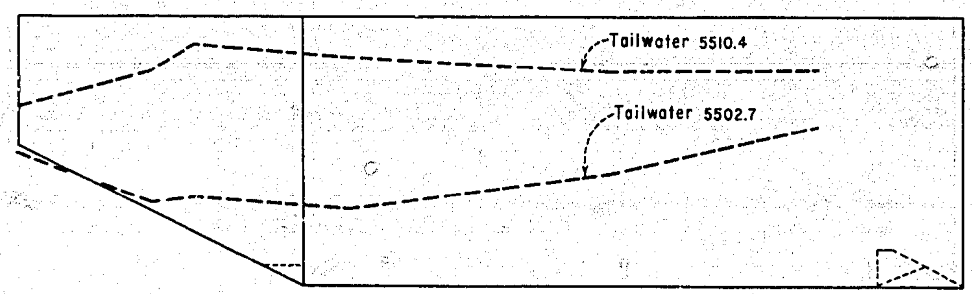
PIEZOMETER LOCATIONS
PLAN



PIEZOMETER LOCATIONS
ELEVATION
Piezometers are located in right training wall of stilling basin



PRESSURE PROFILES
Q = 985 C.F.S.



PRESSURE PROFILES
Q = 620 C.F.S.

WATER MANOMETER PRESSURES--PROTOTYPE FEET OF WATER

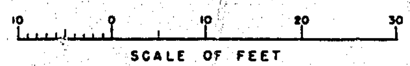
Q = 985 C.F.S. Both gates 100% open

PIEZOMETER NUMBER	TAILWATER ELEVATION 5503.4			TAILWATER ELEVATION 5510.7		
	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE
1	0.2	0.1	0.2	6.9	4.4	5.7
2	10.0	9.6	9.8	14.4	12.5	13.5
3	3.7	3.5	3.6	9.8	8.0	8.9
4	—	—	—	5.7	4.1	4.9
5	5.3	2.8	4.1	14.3	12.7	13.5
6	8.0	5.5	6.8	16.5	14.3	15.4
7	10.1	8.6	9.4	15.7	13.8	14.8
8	—	—	—	6.3	4.5	5.4
9	5.1	2.9	4.0	13.9	10.9	12.4
10	10.7	8.1	9.4	19.6	18.0	18.8
11	13.0	11.4	12.2	21.3	19.6	20.5
12	11.1	9.4	10.3	20.0	17.8	18.9
13	—	—	—	6.5	5.0	5.8
14	5.0	3.4	4.2	13.9	11.2	12.6
15	12.7	10.5	11.6	22.7	20.4	21.6
16	0.6	0.1	0.4	7.2	5.3	6.3
17	7.5	5.8	6.7	14.4	12.7	13.6
18	14.1	12.1	13.1	22.0	19.7	20.9
19	0.7	0.6	0.7	7.5	7.3	7.4
20	8.7	7.2	8.0	15.2	13.5	14.4
21	16.5	16.4	16.5	23.0	22.6	22.8

Q = 620 C.F.S. Right gate 100% open, left gate closed

PIEZOMETER NUMBER	TAILWATER ELEVATION 5502.7			TAILWATER ELEVATION 5510.4		
	MAXIMUM	MINIMUM	AVERAGE	MAXIMUM	MINIMUM	AVERAGE
1	-0.6	-1.0	-0.8	5.0	2.8	3.9
2	15.8	14.5	15.2	19.4	16.7	18.1
3	4.1	3.9	4.0	9.0	7.7	8.4
4	—	—	—	5.7	4.7	5.2
5	-0.1	-0.7	-0.4	14.7	12.5	13.6
6	3.7	3.3	3.5	18.6	16.7	17.7
7	6.1	5.6	5.9	18.5	16.7	17.6
8	—	—	—	6.7	5.8	6.3
9	—	—	—	13.1	10.5	11.8
10	4.6	2.8	3.7	20.7	19.1	19.9
11	7.8	6.4	7.1	22.9	21.2	22.1
12	4.6	2.8	3.7	20.6	18.8	19.7
13	—	—	—	7.0	6.2	6.6
14	0.2	0.0	0.1	14.0	11.7	12.9
15	6.9	5.8	6.4	23.4	21.9	22.7
16	—	—	—	6.8	5.7	6.3
17	4.2	1.8	3.0	14.4	13.1	13.8
18	11.0	8.8	9.9	21.6	20.4	21.0
19	—	—	—	6.9	6.8	6.9
20	7.5	6.4	7.0	14.0	13.2	13.6
21	15.1	15.0	15.1	No Data		

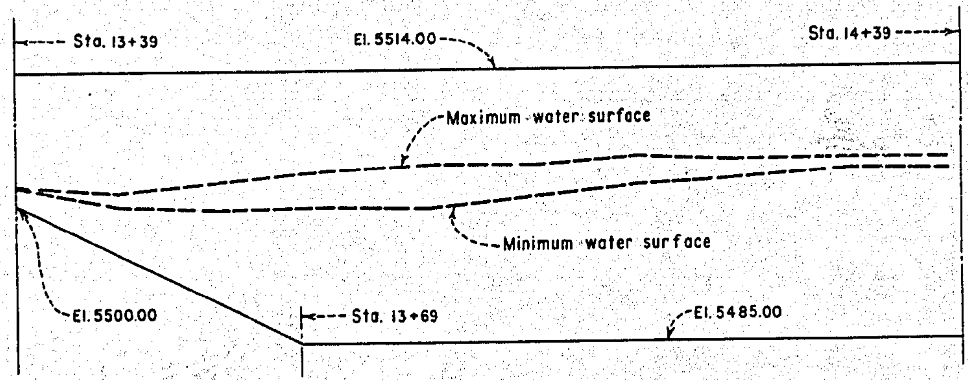
Pressure measured above piezometer opening.
Blank spaces indicate piezometer is above the water surface.



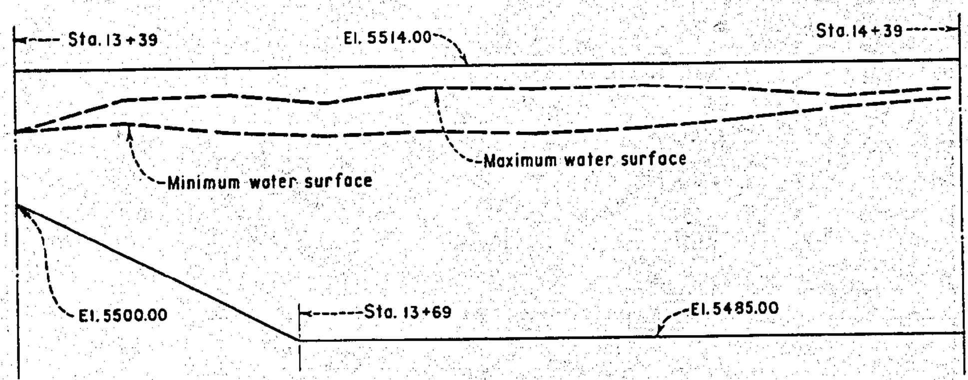
CAUSEY DAM OUTLET WORKS

1:11 SCALE MODEL

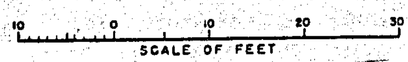
PIEZOMETER LOCATIONS, PRESSURES, AND PRESSURE PROFILES
MAXIMUM DISCHARGES WITH MINIMUM LOSSES IN SYSTEM



Q=783 C.F.S. — TAILWATER El. 5503.0
BOTH GATES 100% OPEN



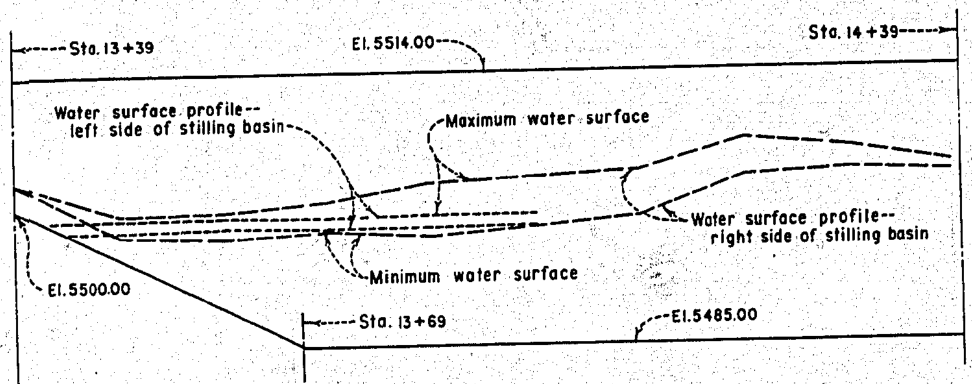
Q=783 C.F.S. — TAILWATER El. 5510.5
BOTH GATES 100% OPEN



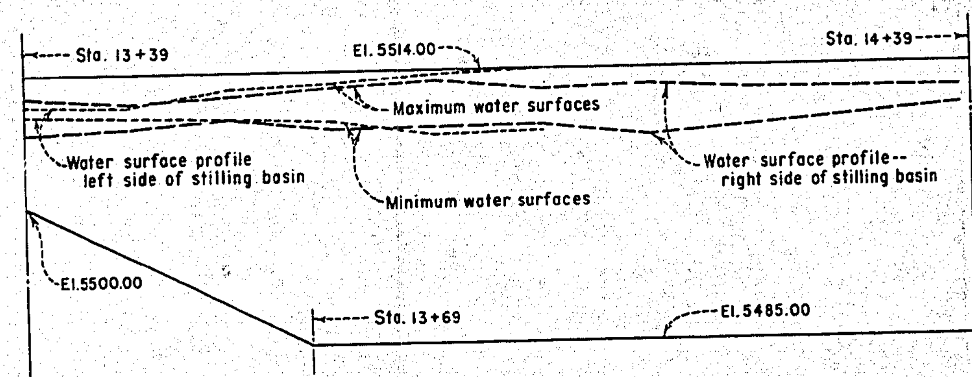
CAUSEY DAM OUTLET WORKS

1:11 SCALE MODEL

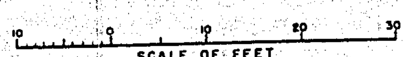
WATER SURFACE PROFILES



Q=554 C.F.S. — TAILWATER El. 5502.5
RIGHT GATE 100 % OPEN — LEFT GATE CLOSED



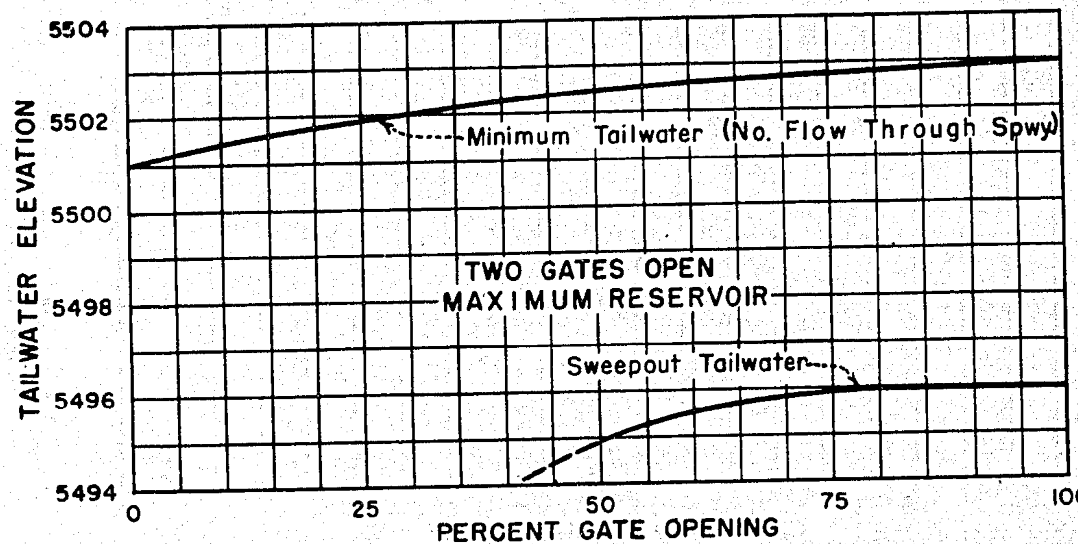
Q=554 C.F.S. — TAILWATER El. 5510.3
RIGHT GATE 100 % OPEN — LEFT GATE CLOSED

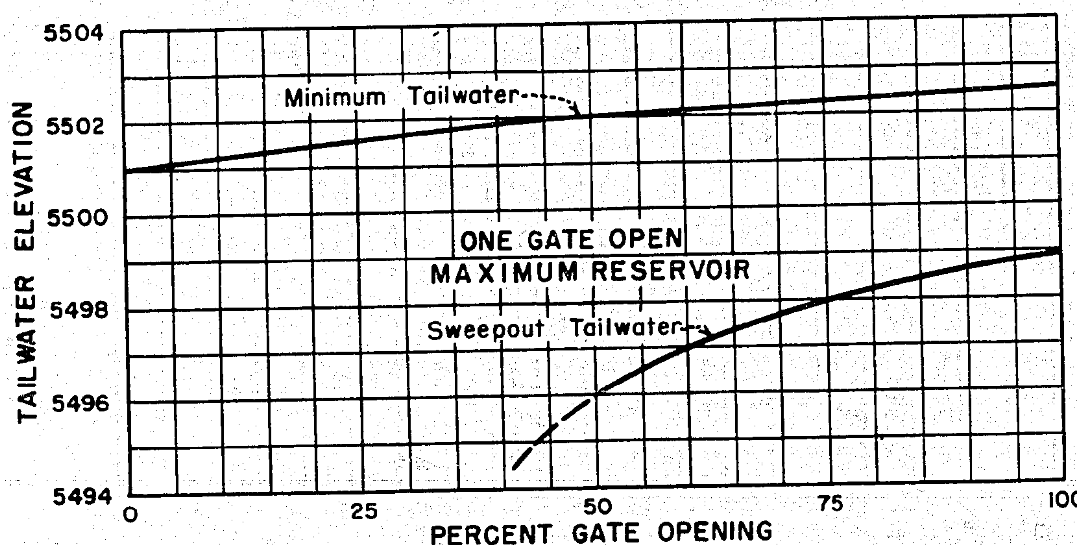


CAUSEY DAM OUTLET WORKS

1:11 SCALE MODEL

WATER SURFACE PROFILES

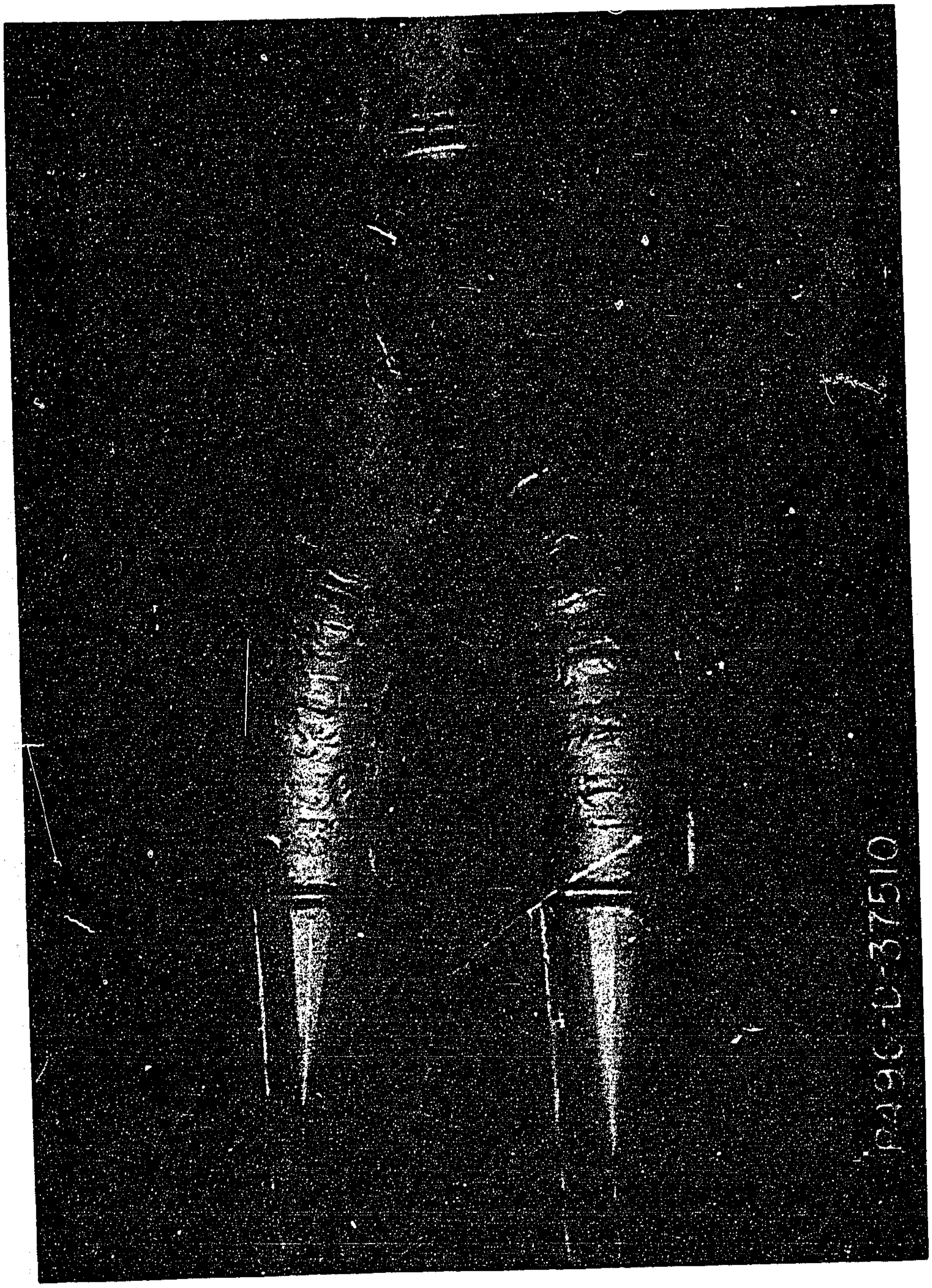




CAUSEY DAM OUTLET WORKS

1:11 SCALE MODEL

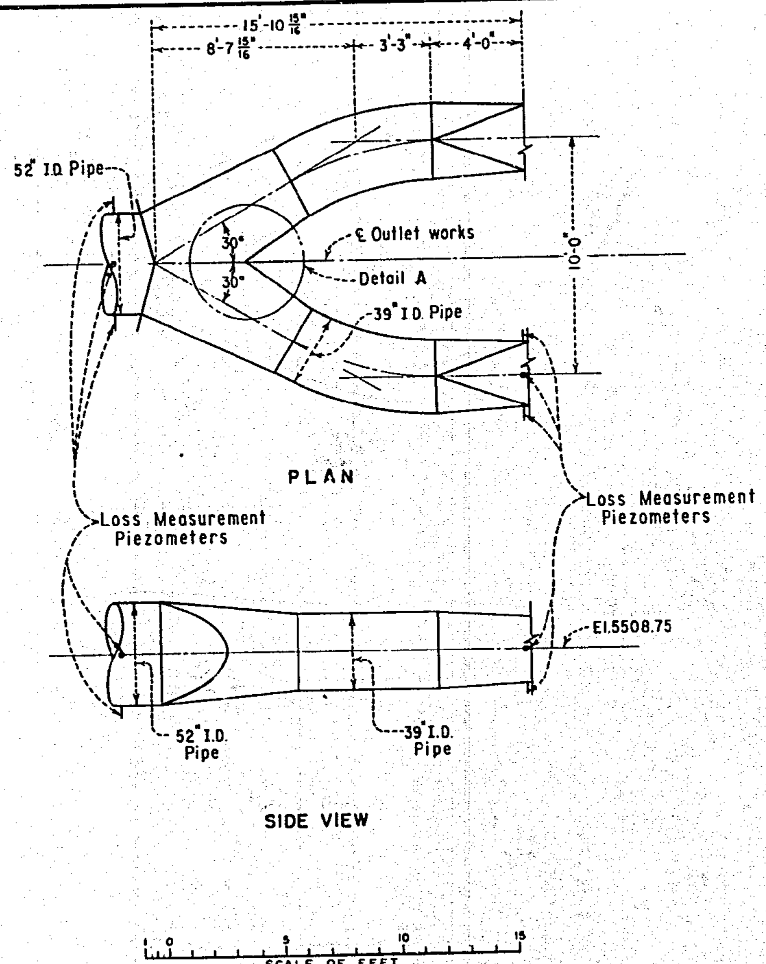
TAILWATER SWEEPOUT CURVES FOR
DISCHARGES WITH NORMAL LOSSES IN SYSTEM

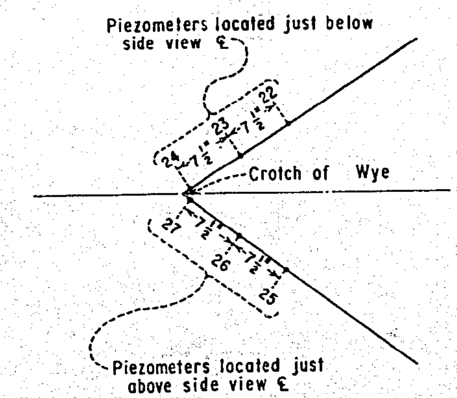


CAUSEY DAM OUTLET WORKS

1:11 Scale Model

Wye-branch Configuration





DETAIL A
PIEZOMETER LOCATIONS

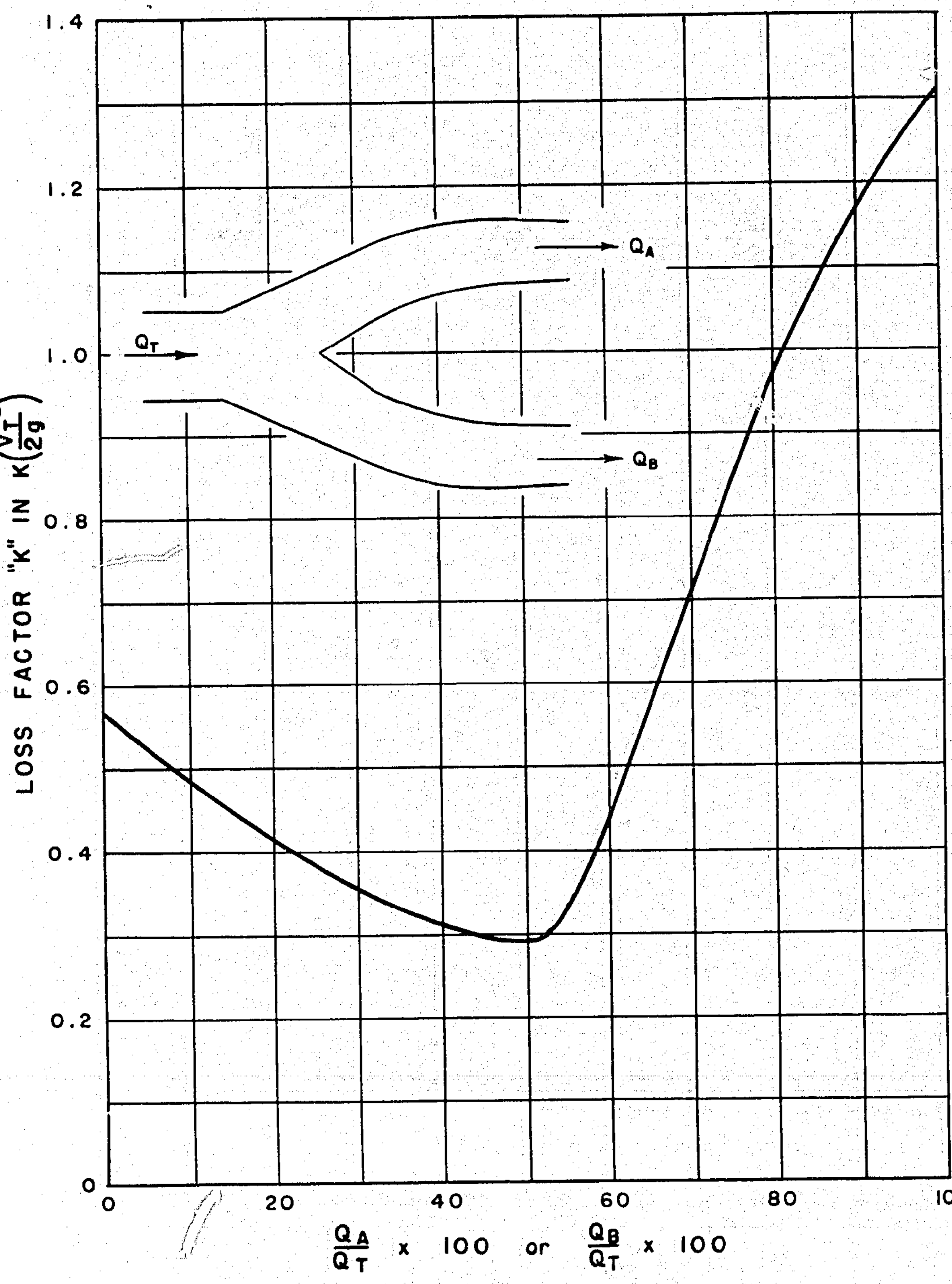
Water Manometer Pressures
Prototype Feet of Water
100 Percent Gate Opening

PIEZO-METER NUMBER	BOTH BRANCHES OPEN	RIGHT BRANCH OPEN	LEFT BRANCH OPEN
22	31.0	93.9	28.3
23	36.8	96.9	22.3
24	49.0	92.4	20.9
25	29.6	32.8	89.4
26	34.9	26.8	92.4
27	40.4	23.9	92.4

Instantaneous Dynamic Pressures
Prototype Feet of Water
100 Percent Gate Opening
Piezometer 27

	BOTH BRANCHES OPEN	RIGHT BRANCH OPEN
MAXIMUM	36.0	65.5
MINIMUM	28.1	−7.7
AVERAGE	31.9	28.6

CAUSEY DAM OUTLET WORKS
1:11 SCALE MODEL
PRESSURES IN WYE BRANCH



CAUSEY DAM OUTLET WORKS

1:11 SCALE MODEL

WYE BRANCH LOSSES